TR-210

TECHNICAL REPORT

ASWEPS REPORT NO. 15

DETAILED THERMAL STRUCTURE OF THE WESTERN GULF STREAM REGION

DECEMBER 1968

NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON, D. C. 20390
Price 60 cents

ABSTRACT

Several thermal structure characteristics observed by oceanographic research vessels and aircraft are displayed and discussed. A series of airborne radiation thermometer (ART) flights conducted in April 1967 show detailed structure and pattern changes near the northern boundary of the Gulf Stream. Thermal changes were related to two contrasting weather patterns.

Since ART data define only surface temperature patterns, a ship survey was conducted in October and November 1967 to obtain vertically as well as horizontally distributed data. The ship survey was repeated, obtaining a total of almost 1,000 BT's. Cross sections of the data show that advection indicated by the ART survey extends to considerable depth. Three major features were observed: a meander developing in the Gulf Stream, a cold ring south ot the stream, and a warm eddy north of the Stream. The general flow was eastward, but a few features were found to drift westward.

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FOREWORD

The Naval Oceanographic Office (NAVOCEANO) is conducting research in support of the Antisubmarine Warfare Environmental Prediction Services (ASWEPS) in the western North Atlantic. From this research has evolved a series of technical reports designed to disseminate significant research results. Early research demonstrated that the dynamic processes at the northern edge of the Gulf Stream should be thoroughly investigated because the horizontal energy exchange and the complex thermal structure in this area are of considerable importance to the ASW effort.

This report is based on an investigation of the structure and dynamics of the Gulf Stream in 1967. Continuing NAVOCEANO study of the dynamics of the Gulf Stream is reported in a monthly publication, The Gulf Stream, which contains current research results and may be consulted to supplement information reported by ASWEPS technical reports.

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INTRODUCTION

During 1967 the U.S. Naval Oceanographic Office conducted two surveys specifically designed to determine thermal structure characteristics in and near the Gulf Stream. The main interest was movement of the northern edge of the Gulf Stream and study of the interaction of the Gulf Stream and Slope Water to the north of the stream. Meanders have been discovered along the northern boundary of the Gulf Stream (The Gulf Stream, Vol. 1, No. 7), and many small-scale features exist north of the Gulf Stream (Fuglister, 1963). At times, the two appear to be independent of each other. Ordinary data do not permit demonstration of feature characteristics, such as origin, width, depth, and propagation speed. Without these basic facts, adequate predictions are not possible.

The two 1967 surveys were designed to answer some of these questions by providing a good data base. The surveys, one by aircraft and one by ship, provided good examples showing the Gulf Stream wall, its fluctuations, and movement of warm and cold features north and south of the Gulf Stream, as well as some interesting atmospheric effects.

The first survey was conducted in April by a Naval Oceanographic Office aircraft using an airborne radiation thermometer (ART) to obtain sea surface temperatures. The track, covering the area indicated in figure 1, was planned so that it would penetrate the Gulf Stream, outline the northern edge of the stream, and show some detail north of the edge. The track was flown on 4 consecutive days (10, 11, 12, and 13 April). Flying weather was good throughout the period, but the weather pattern changed considerably.

The ART survey pointed out that data at depth were needed to adequately determine oceanographic processes, thus a second survey was planned for October and November to provide such data using mechanical and expendable BT's. This survey was conducted by the USNS GILLISS over a 4-week period from 17 October through 9 November 1967 in the region shown in the right of figure 1. The GILLISS survey was repeated, each point being observed after an interval of approximately two weeks.

The survey area was designed to enable investigation of the Gulf Stream, water mass movement to the north, and relative inactivity to the south. Good weather prevailed; the data sample was quite complete and not adversely affected by bad observing conditions. The time interval for the two surveys should be kept in mind; the ART changes are daily, but the ship changes occurred over a 2-week period.

AIRBORNE RADIATION THERMOMETER SURVEY

Aircraft sensors are a luxury that has only recently become available to oceanographers. This luxury provides the ability to observe

large areas in minimum time; however, aircraft sensors are limited in subsurface observations. The April series of flights proved to be extremely valuable in pointing out two major characteristics: existence of east-west oriented surface features north of the Gulf Stream boundary and wave-like motion of the boundary. Movement of features north of the stream was not discernible, because the time covered by the survey was too short. However, absolute temperature changes due to atmospheric conditions were observed within features.

Weather conditions during the ART survey are shown in figure 2. On 10 April the region was dominated by a warm anticyclone with increasing southerly flow as the day progressed. Before the flight on 11 April, a strong cold front swept over the area causing a drop in air temperature of 10°C. Cooling continued through the 12th and 13th with decreasing northerly winds.

Figures 3 and 4 show the aircraft tracks and sea surface temperature (SST) analyses for the 10th and 11th, respectively. The first day had the fewest legs (indicated by the thin black line with arrows), because tracking was required to establish the survey area. Determination of the track before the flight on the following days resulted in more time for surveying the area. The chart for the 10th shows the location of the tight gradient zone which delineates the northern boundary of the Gulf Stream. This chart also contains the highest temperatures and is for the same day that the warm high dominated the area.

Features worth noting on the 11th include the location of the northern boundary south of 37°N, a cool filament lying just north of the stream, a warm cell north of the cool filament, and overall cooling from the 10th. The 10°C area at 72.5°W reflects this cooling. The Advection ? average drop in water temperature was about 1°C in the warm and cold features north of the stream, but the stream temperature showed no significant decrease. The lack of cooling in the stream is due to rapid advection of warm water.

The pattern for the 12th (figure 5) is similar to that of the 11th with minor important changes. The northern boundary in the western portion of the area has progressed northward to just south of 37°N, and the cooling of features north of the stream has subsided. The cool water just north of the Gulf Stream is becoming more prominent. The warm cell still exists, and a wave has developed along the wall.

By the 13th (figure 6), the last day of observations, two days of convective and mechanical mixing have passed and features are well-defined. The northern boundary moved north of 37°N to a point only 35 km south of the warm cell. This major wave apparently progressed at a rate of 0.3 m/sec, and its wave length appears to be about 160 to 200 km. This wave speed is greater than found in earlier work (The

Gulf Stream, Vol. 1, No. 7) and its wavelength is smaller. Figure 7 re-emphasizes the wave movement south from the 10th to the 11th, then 2 days of northern progression from the 11th to the 13th. The movement of the northern boundary is counter to the wind drift on the 12th and 13th.

Calculations were made to determine vertical thermal structure changes due to atmospheric change (north of the Gulf Stream). Since the technique (Gemmill and Nix, 1965) requires knowledge of the initial ocean thermal structure with depth, a guess of the structure based on historical BT's was made. Several tests of mixed layer depth indicated that the amount of observed cooling would deepen a 15-meter layer to 30 meters during the survey period.

Analyses of ART data are good representations of the sea surface temperature pattern. However, vertical thermal structure can only be implied from ART analyses, and, in order to fully understand the three-dimensional changing ocean, temperature observations with depth must be provided.

THE USNS GILLISS SURVEY

The USNS GILLISS survey was conducted in two identical phases (I and II) with the objective of observing changes that occurred over a 2-week period. Of approximately 1,000 BT's collected, half were taken by mechanical BT's to a depth of 300 meters; the remainder were taken by shipboard expendable BT's (SXBT) to 450 meters. Ten zonal legs were surveyed (figure 1) from 36°N to 40°N between 65°W and 69°W, with observations about 8 km apart. Each leg required nearly one day to transit. A special crossing of the Gulf Stream was made from 39°20'N to 38°34'N and back to 39°N along 65°W. Observations were taken at 1-km intervals during this crossing.

Horizontal temperature analyses were drawn for the sea surface, 200 meters, 450 meters, and the mixed layer depth. Cross sections were drawn for each zonal leg for both phases. Changes between phases appear in the horizontal analyses and cross sections, but it should be remembered that in composite analyses there are time distortions. This factor is insignificant in the cross sections, because each section is based on data taken within a 24-hour period.

A. WEATHER INFLUENCES

During the early part of phase I, two large cool anticyclones moved eastward from the U.S. to dominate the area. The storm track was located close to the east coast of the U.S. and did not influence the area. On 30 October an intense cyclone developed near the northeast corner of the

area (41°N,63°W) and produced strong northwest winds at 15 to 20 m/sec and cool air temperatures near 12°C. On the following day, the wind slowly decreased to 10 m/sec and shifted to the northeast; the temperature rose to 18°C. During the remainder of the survey the area was dominated by weak weather systems.

The direct effects of weather on the ocean are difficult to determine. The sea surface temperature pattern during phase I did not represent the subsurface thermal structure. No major storms had influenced the area for some time, thus the surface layer was not thoroughly mixed, masking the major features. At 200 meters, however, below most weather influences, the features are much more evident. During phase II, the surface developed much clearer features due partially to the two days of wind mixing by the storm of 30 and 31 October.

Calculations were again made to predict vertical temperature changes due to weather by use of the Gemmill and Nix model. The sea surface in general would have cooled 0.5° to 1.5°C, if advection were not a factor. However, it will be shown that the water both warmed and cooled to a far greater extent, implying that advection is the more important mechanism for short-term temperature changes.

B. DESCRIPTION OF ANALYSES AND CHANGES

1. Horizontal Analyses

To aid three-dimensional portrayal of the more important features, they have been designated as follows:

(A) Gulf Stream northern boundary
(B) Warm eddy near 39.5°N,68°W
(C) Cold ring near 36.5°N,67°W
(D) Surface cold tongue at 40°N,67°W
(E) Subsurface cold tongue at 40°N,67°W
(F) Warm cell at 37°N,66°W
(G) Sound channel region at 40°N,68°W

The horizontal analyses (figures 8, 9, and 10) of phase I revealed several major features. The northern boundary of the Gulf Stream (A) is identified by a strong temperature gradient zone oriented east-west across the center of the area. The gradient is weakest (3° to 5°C) at the surface and strongest (10°C) at 450 meters. The boundary slopes southward at a rate of 1:300. The center of the Gulf Stream on the surface is warm (24°C) water. Evidence of a weak countercurrent is located south of the Gulf Stream with slightly cooler water (<24°C). The countercurrent is not evident at depth.

Two isolated water masses were also detected during phase I: a warm eddy (B) north of the Gulf Stream near 39°N,68°W and a cold ring

(eddy) (C) south of the stream at 36°30'N,67°W. Neither feature was observed at the surface, although the warm eddy is in an area of relatively warm surface water. The cold ring appears in an area where horizontal uniformity is expected. A similar ring was observed by ART in March 1967 as it developed from a Gulf Stream eddy (The Gulf Stream, Vol. 2, No. 4). Between March and November, data obtained from cruises of the R/V Crawford led Fuglister (personal communication) to conclude that the ring observed from the aircraft in March is the same ring observed by the GILLISS in November.

The temperature gradient between the warm eddy and the surrounding water is greatest at 200 meters, where its center is 6°C warmer. The cold ring exhibits strong intensification with depth. There is no evidence of the ring at the surface, its center is 5°C colder than surrounding water at 200 meters and 7°C colder at 450 meters.

A surface cold tongue (D) is located immediately east of the warm eddy. This feature is not as evident as the previously discussed features but will become more significant in phase II analyses.

The surface pattern is less organized and has weaker gradients than the deeper levels. Prior to the survey, the surface was exposed to weak variable weather conditions which produced a confused sea surface temperature pattern.

Phase II indicates some major changes from conditions during phase I. The northern boundary of the Gulf Stream (A) has developed a large meander near 38°N,68°W. The northern boundary has a stronger temperature gradient on the surface, is broader at depth and slopes southward as it did in phase I. The Gulf Stream boundary weakens considerably to the east of 66°30'W, although it follows the 24°C isotherm just south of 39°N as shown by the 200- and 450-meter analyses.

In the northeast part of the area, temperatures have increased by as much as 5°C through 450 meters, and a deep flow from the east now appears over this area. The warm-water advection is probably part of a large meander. This influx of warm water is responsible for obscuring the Gulf Stream on the surface.

The cool feature (D) described briefly in phase I has become part of a major southward intrusion of cold water. The contrast between the cold intrusion and the warm water of phase I is so great that a strong gradient zone has formed north of the Gulf Stream.

The warm eddy (B) is now evident at the surface even though it has cooled from 21°C to 19°C. The cold intrusion does not appear at 200 meters. However, a subsurface cold tongue (E) occurs east of 67°W at 40°N. Although the surface (D) and subsurface (E) cold tongues appear to be the same feature, they will be shown to be separate features in the cross sections.

The cold ring (C) in phase I has apparently disappeared by the time of phase II. The cold water near 37°N,66°30'W at 450 meters may be a remnant of this ring entrained by the Gulf Stream, or the ring may possibly have moved out of the area entirely. A warm cell (F) at 200 meters overrides cold water at 450 meters near 37°N,66°W.

2. Vertical Cross Sections

Further insight into the three-dimensional structure and change in the Gulf Stream region can be gained from cross sections drawn for each leg of each GILLISS phase. These cross sections contributed additional knowledge of the thermal structure that was not apparent from the horizontal analyses.

The northernmost cross section at 40°N (figure 11, phase I) shows more complexity than was apparent in the surface and 200- and 450-meter analyses. A very cold feature (E) appears near 67°W at 50 meters. The cold water is weakly evident at the surface (D) and at 200 m. More subsurface cold water is present near 69°W.

The cross section along 39°40'W (figure 12, phase I) reveals the same cold feature (E) near 67°W. The warm eddy (B) which appeared in the horizontal analyses is now evident near 68°W. Farther south, along 39°20'W (figure 13, phase I), the cold feature (E) is not apparent at 67°W; but the southern portion of the warm eddy is apparent.

The cross section along 39°N (figure 14, phase I) shows no significant features, but along 38°30'N (figure 15, phase I) the northern edge of the Gulf Stream appears near 67°W. The Gulf Stream, identifiable as the 24°C water, is located just south of this section from 69°W to nearly 67°W, then just north of this section to 65°W (figure 8). The wall of the stream is the sharp gradient zone extending from the surface at 67°W to 120 meters at 65°W.

The thermal structure of the Gulf Stream is much simpler along 38°N (figure 16, phase I). Isotherms become more uniform and inversions are absent, but there is a hint of the Gulf Stream boundary near 69°W, where cold water appears at depth. The temperature of the surface layer in this section is greater than 24°C, indicating that it is the Gulf Stream. The next two sections at 37°30'N (figure 17, phase I) and 37°N (figure 18, phase I) are generally similar to the section along 38°N, but these sections are south of the center of the Gulf Stream, with surface temperatures of 24°C or less. The cold water near 450 meters along 37°N at 67°W is part of the cold ring (C) discussed earlier and is clearly evident at 36°30' (figure 19, phase I). The section along 36°N (figure 20, phase I) is similar to others south of the Gulf Stream. Note that the temperature north of the stream was near 6°C along the bottom of the section (figures 11 through 15, phase I), while bottom temperatures in the stream and south of the stream were greater than 16°C.

Earlier discussion of the horizontal analyses revealed changes between phases I and II: the cross sections emphasize these changes. The cross section at 40°N (figure 11, phase II) shows significant changes after two weeks. The subsurface cold feature (E) has drifted about 20 km eastward, while the surface feature (D) (figure 8) indicates a southwestward advance of cold water. From 67°W to 69°W between 50 and 100 m, the thermal structure is complex with some cold shelf water (10°C) intruding at this depth. This cold intrusion has created an extensive area of strong sound channels (G). A study of the seasonal variations of this phenomenon has been presented by Cresswell (1967). As previously discussed, the surface cooled by as much as 8°C. Warming is noted at all depths over the eastern half, particularly at 65°W. Many of the same changes occurred along 39°40'N (figure 12, phase II). Warming has occurred to the east and the subsurface cold feature (E) moved eastward about 20 km, but the sound channel region (G) has much less horizontal extent. Southerly movement of the sound channel region is being blocked partly by the deep warm eddy (B) that has moved westward about 20 km. The southern portion of the warm eddy appears along 39°20' (figure 13, phase II). The Gulf Stream wall is south and the warm eddy is north of the cross section along 39°N (figure 14, phase II). The thermal structure along 39°20' is fairly uniform for its position in relationship to the Gulf Stream and Slope Water. The warming evident along the eastern half of the northern sections has diminished considerably.

The cross sections along 38°30', 38°00', and 37°30'N, figures 15, 16, and 17, phase II, respectively, all show the Gulf Stream meander and have similar characteristics. They differ only in respect to where they cut through the meander. These cross sections should be viewed in conjunction with figures 8, 9, and 10, the surface and 200- and 450-meter analyses, respectively. The cold Slope Water, originally observed only north of 38°N, has now pushed southward across 38°N at all depths. Its southward advance appears in the cross section at 37°30'N as it intrudes beneath the warmer water. Farther south (figures 18 and 19, phase II), a deep warm cell (F) is associated with an isothermal layer of 120 meters. The structure of this cell is similar to that observed on the edge of the area during phase I between 36°N and 36°30'N at 65°W and may be the same cell. Cold water directly beneath the warm cell at 37°N could be either the advancing Gulf Stream meander or the remnants of the cold ring (C). The southernmost cross section along 36°N (figure 20, phase II) is typical of the Sargasso region.

3. Special Gulf Stream Cross Sections

During phase I, a special crossing of the Gulf Stream was made from 39°20'N to 38°34'N and back to 39°N along 65°W (figure 21). BT's were taken at 1-km intervals, and the positions are plotted on the figure. The cross sections, by virtue of covering a short horizontal distance, show the complex structure of the wall. The cross sections are similar

to those shown by Mazeika (1968).

4. Mixed Layer Depth Analyses

The mixed layer depth analyses shown in figure 22 were constructed by using an empirical layer depth analysis model developed by the Naval Oceanographic Office ASWEPS program. This model is water mass oriented but also includes rules for layer depth analysis in areas of water mass interaction and other peculiarities, i.e., sound channels and heat traps. This model is presented by Thompson and Anderson (1965).

Upon first inspection, the GILLISS layer depth data appear to be random. When the two phases were taken separately and analyzed using the sea surface temperature chart as a water mass guide, a reasonable representation of the mixed layer depth was obtained. The data show that layer depth patterns are not as continuous as previously expected, but a reasonable pattern was deduced.

Mixed layer depth is a function of the physical properties of the water mass and the dynamic processes acting on and in the water mass. The significance of each of the various processes varies with season, locality, and synoptic weather situations.

The GILLISS survey was made during a normally cooling period and a period of transition from summer to winter oceanographic conditions. Heat budget calculations for the survey period indicate an overall heat loss from the surface layers. This factor alone indicates that mixed layers would be expected to deepen. Figure 22 shows that mixed layer depths became both deeper and shallower between phases.

Further inspection of the various horizontal and vertical analyses (figures 8 through 21) leads to the conclusion that layer depth changes between surveys are primarily due to water mass advection. Two types of advection changes of the layer depth are prominent. One is water mass change with the layer depth characteristics of the new mass replacing those of the original water mass. An example of this change is the deep layer of 120 meters located at 36°30'N,65°W in phase I and at 37°N,66°W in phase II (figure 22). The second type of advective influence on layer depth is due to layering of water masses at a given location. Such conditions are usually associated with gradient zones between water masses. The zero layers (shaded areas in figure 22) were mainly formed by this phenomenon.

The deepest layers during both phases are associated with the warmest water, e.g., the Gulf Stream and eddies. The deep Gulf Stream core (>60 meters) can be easily followed east-west across the center of the area in phase II. The warming near 40°N,65°W is associated with deep layers similar to those of the Gulf Stream, thus supporting the argument

that this warming is advective and is part of a Gulf Stream meander. Several isolated deep warm cells occurred south of the Gulf Stream in both phases, and the warm eddy had deep layer depths during phase II.

A persistent feature south of the Gulf Stream, the relatively shallow area (<30 meters) near 38°N between 65°W and 67°W, indicates a slow-moving countercurrent which is influenced significantly by the weather. This region has cooled slightly (1°C) during the survey, thus the layers would be expected to be deeper in phase II.

SUMMARY

The fine structure and water mass movements in the Gulf Stream region were shown through these surveys. Wave-like motion of the northern boundary of the Gulf Stream wall was demonstrated, shallow warm and cool filaments were located immediately north of the stream, a major warm eddy drifted westward, a cold intrusion pushed south to form a secondary front, and a subsurface cold ring drifted south of the stream. Atmospheric effects were evident but were overshadowed by water mass advection. The ability of an airborne radiation thermometer to show changes in the Gulf Stream by means of a series of synoptic analyses has been shown. Ship data, though not synoptic, can depict the three-dimensional structure in the changing Gulf Stream region.

REFERENCES

1. Cresswell, G. M. Quasi-synoptic monthly hydrography of the transition region between coastal and slope water south of Cape Cod, Massachusetts. Woods Hole Oceanographic Institution, Reference No. 67-35, July 1967.

2. Fuglister, F. C. Gulf Stream '60. Progress in Oceanography 1, 265-383, 1963.

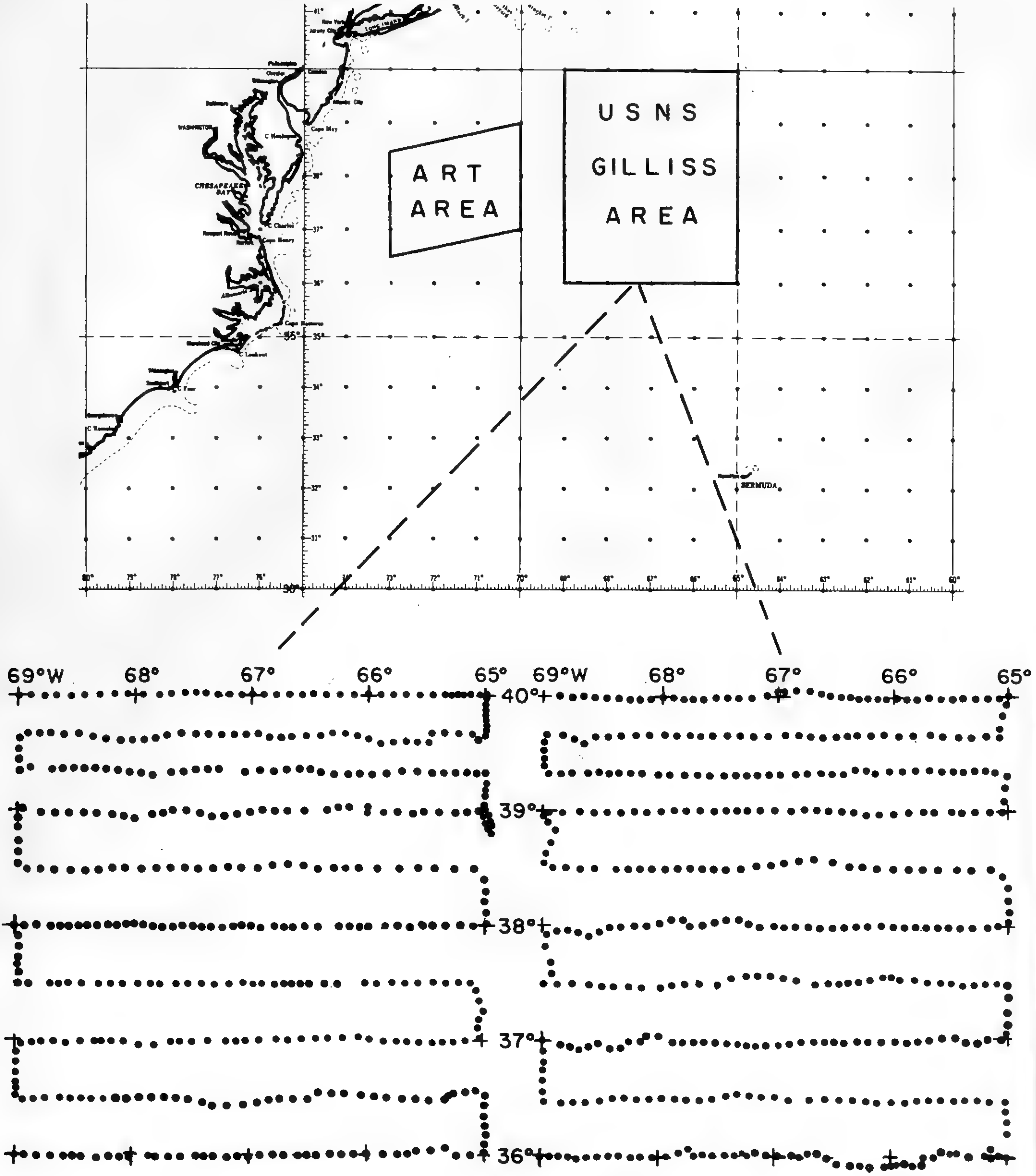
3. Gemmill, W. H. and D. W. Nix. A Heat Budget Model for Prediction of Vertical Temperature in the Ocean. U. S. Naval Oceanographic Office, Informal Manuscript Report No. 0-42-65, Oct. 1965, Unpublished.

4. Mazeika, P. Some Features of the Gulf Stream off Chesapeake Bay in the Spring of 1963. Fishery Bulletin: Vol. 66, No. 2, pp. 387-423, Feb. 1968.

5. Thompson, B. J. and R. Anderson. U. S. Naval Oceanographic Office, Subjective Layer Depth Analysis Model, U. S. Naval Oceanographic Office, Informal Manuscript Report No. 0-25-65, Oct. 1965, Unpublished.

6. U. S. Naval Oceanographic Office. The Gulf Stream Summary, Vol. 1, No. 7, July 1966.

7. ------. The Gulf Stream Summary, Vol. 2, No. 4, April 1967.



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BATHYTHERMOGRAPH LOCATIONS

FIGURE 1 LOCATOR CHART

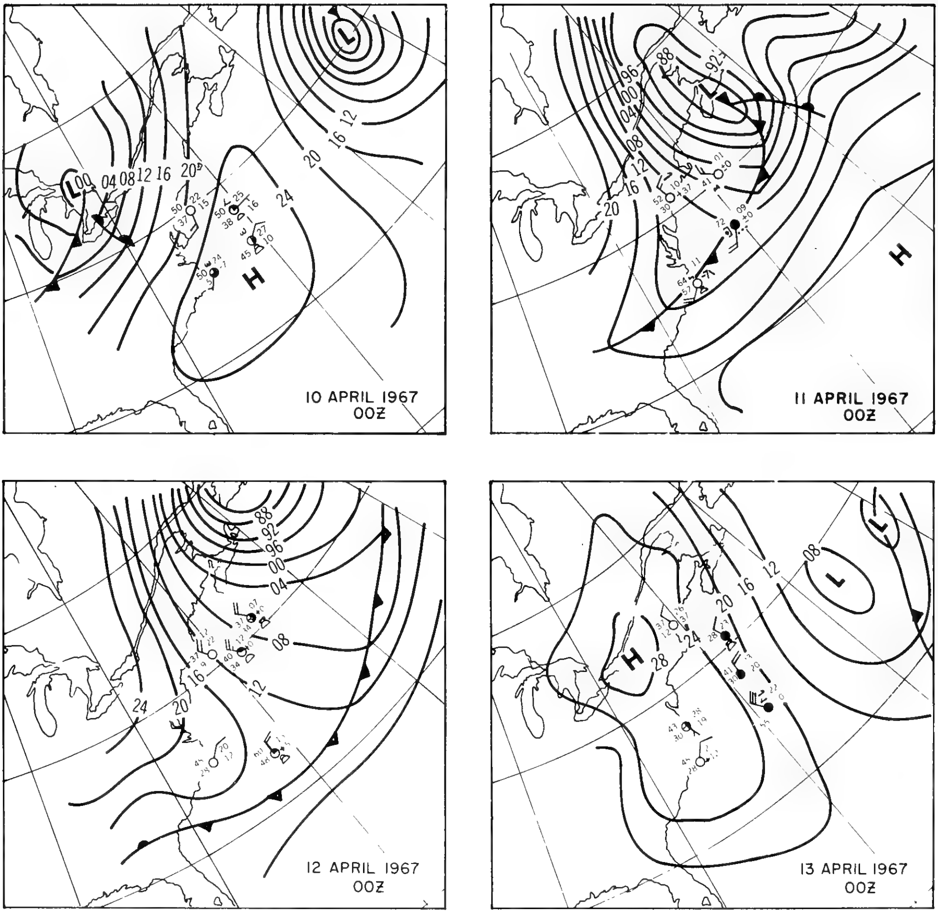

FIGURE 2 WEATHER DURING ART SURVEY

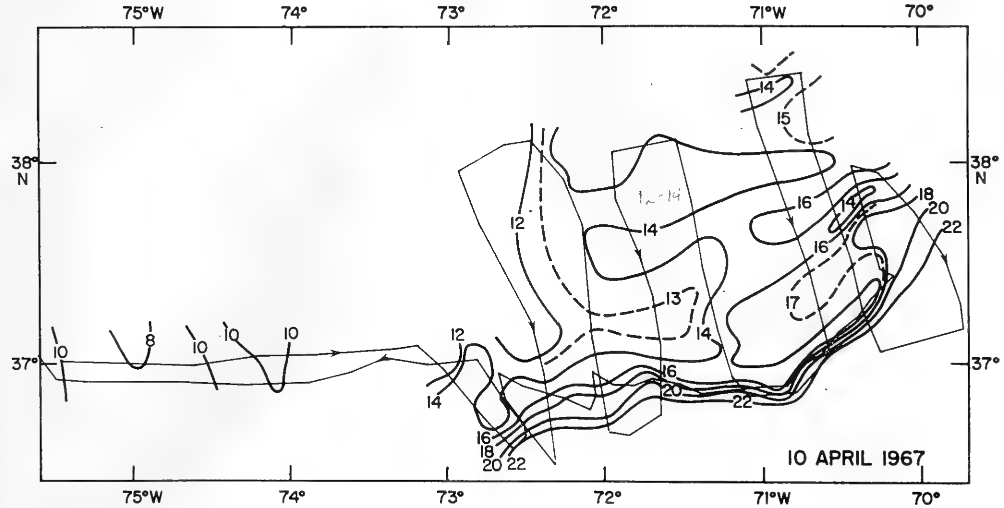

FIGURE 3 SST (°C) ANALYSIS OF ART DATA

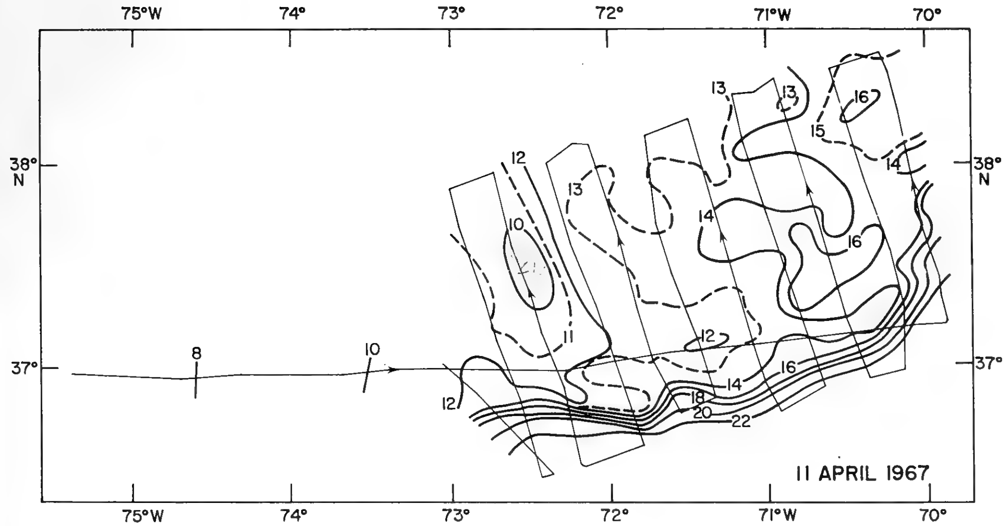

FIGURE 4 SST (°C) ANALYSIS OF ART DATA

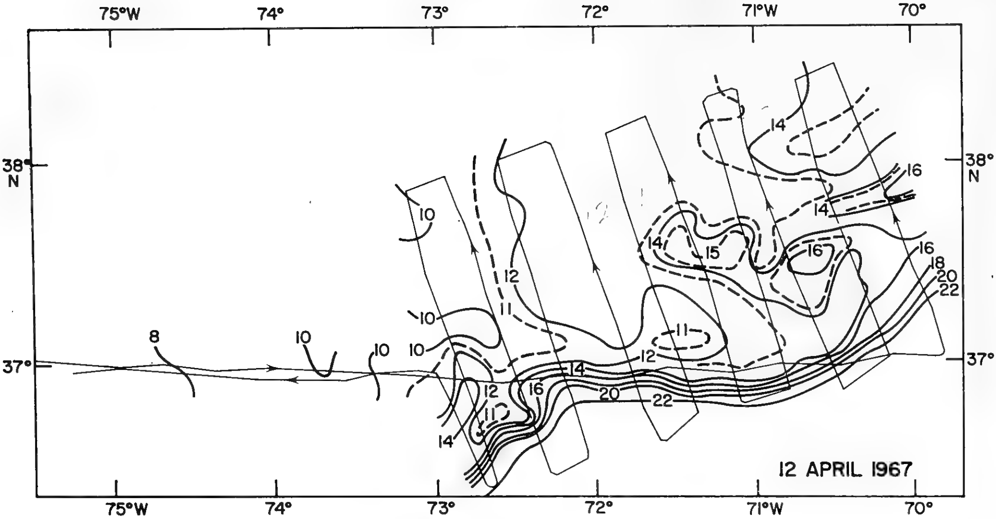

FIGURE 5 SST (°C) ANALYSIS OF ART DATA

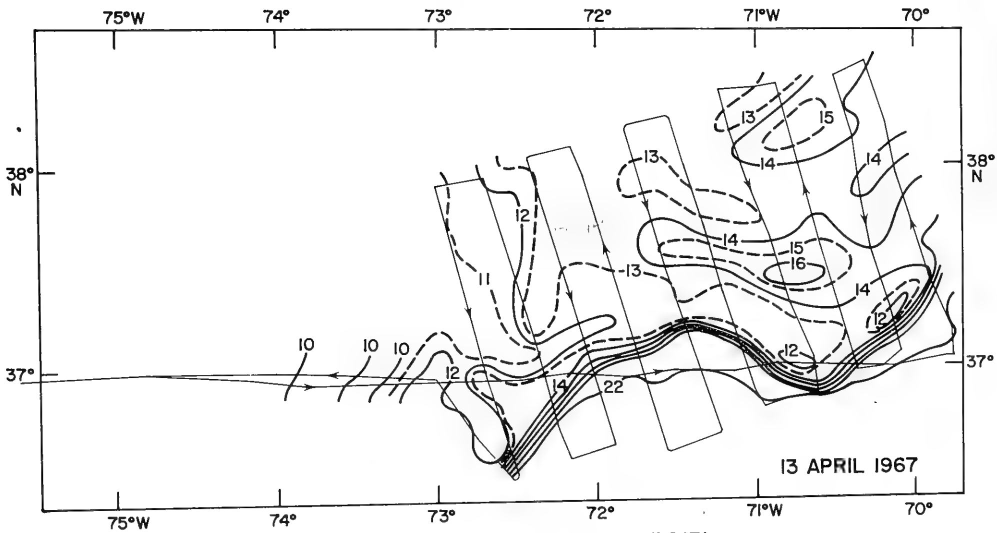

FIGURE 6 SST (°C) ANALYSIS OF ART DATA

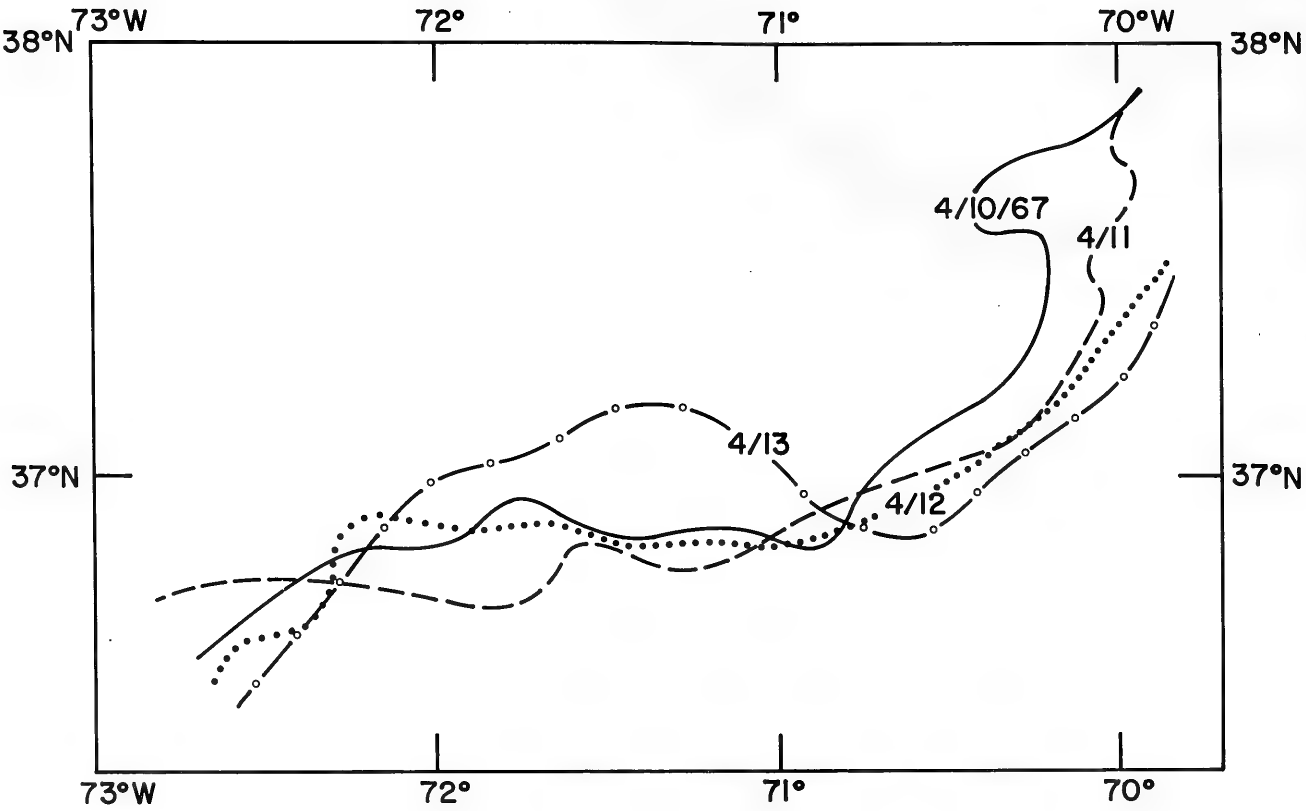

FIGURE 7 DAILY POSITION OF THE 18° C ISOTHERM 10–13 APRIL 1967

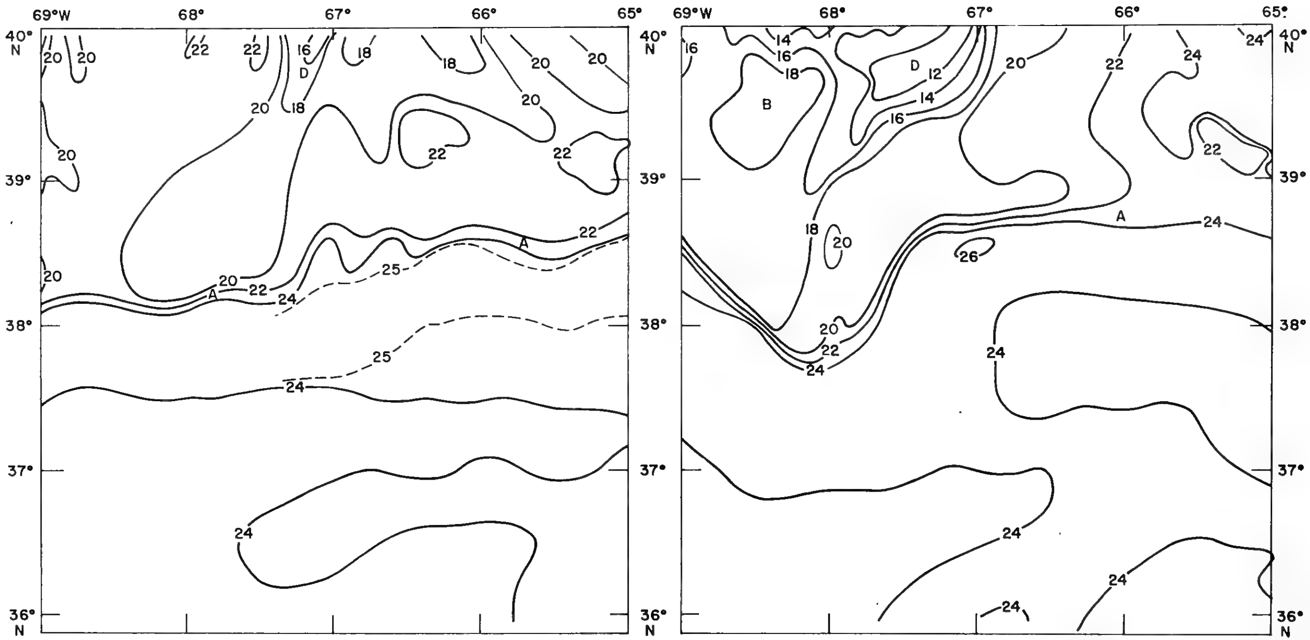

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FIGURE 8 COMPOSITE SST ANALYSES USNS GILLISS DATA (°C)

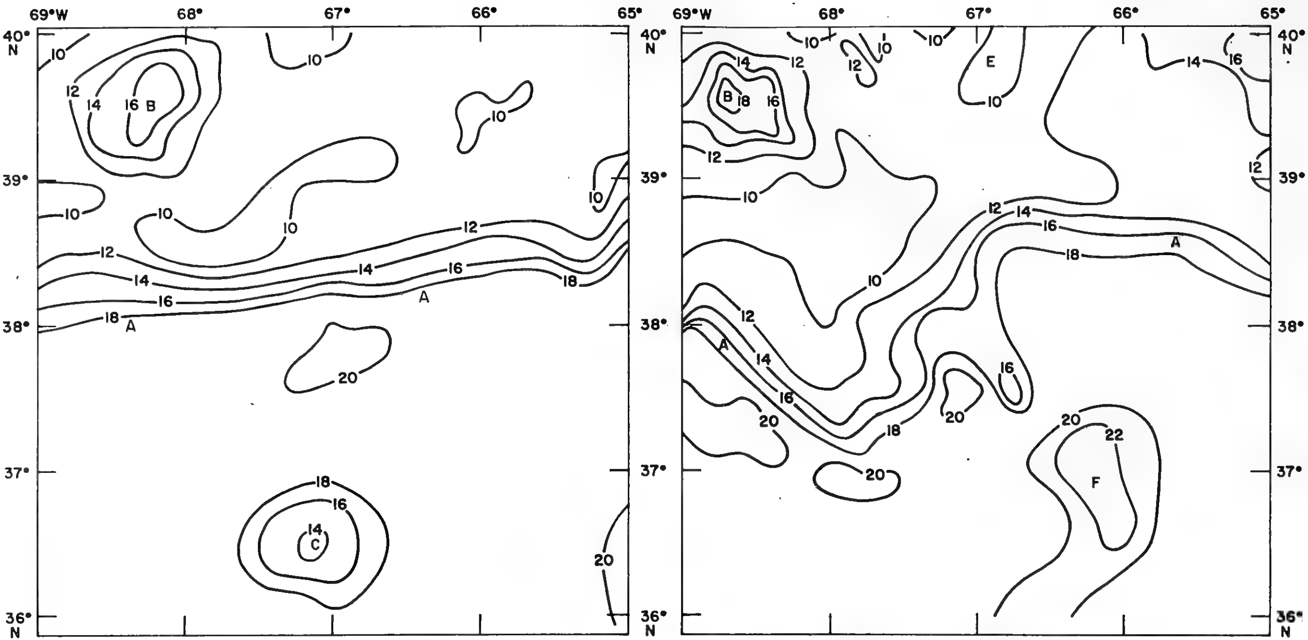

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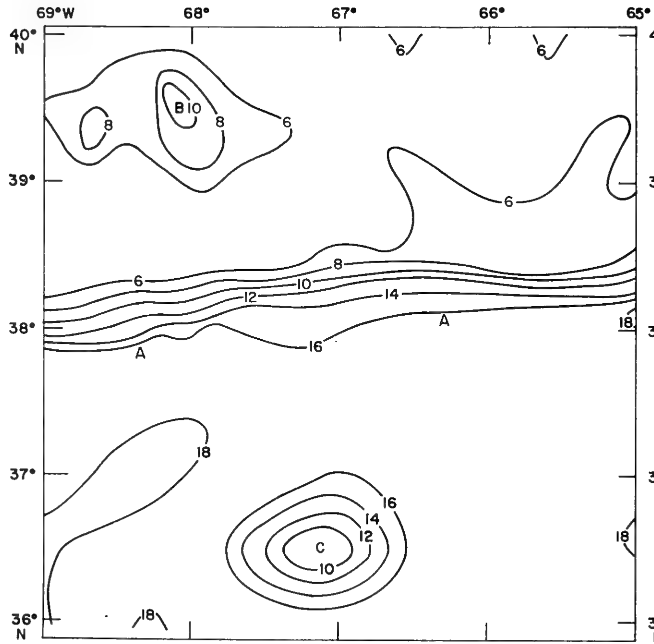
FIGURE 9 COMPOSITE 200-METER TEMPERATURE ANALYSES USNS GILLISS DATA (°C)



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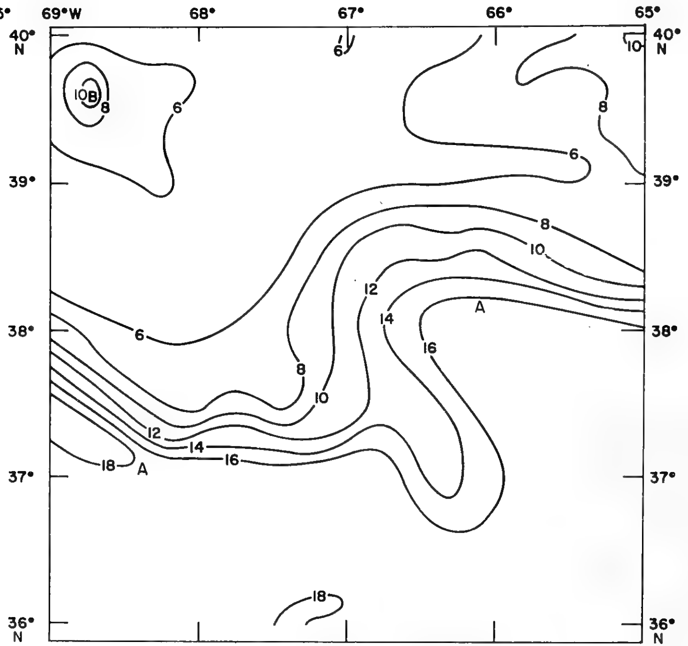

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FIGURE 10 COMPOSITE 450-METER TEMPERATURE ANALYSES USNS GILLISS DATA (°C)

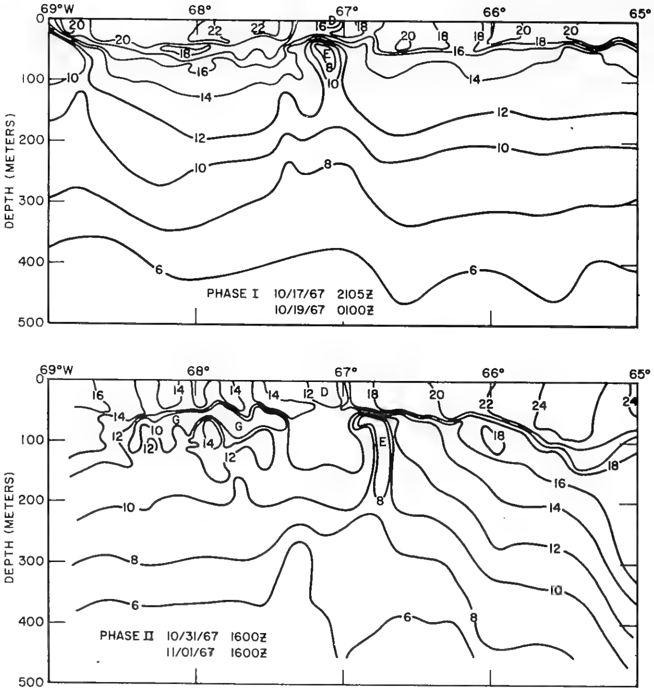


FIGURE 11 TEMPERATURE CROSS SECTIONS ALONG 40°00'N (°C)

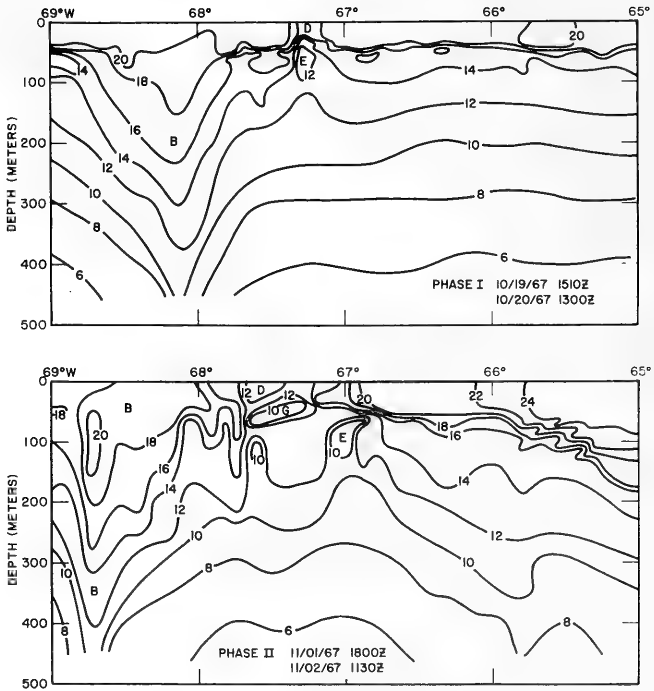


FIGURE 12 TEMPERATURE CROSS SECTIONS ALONG 39°40'N (°C)

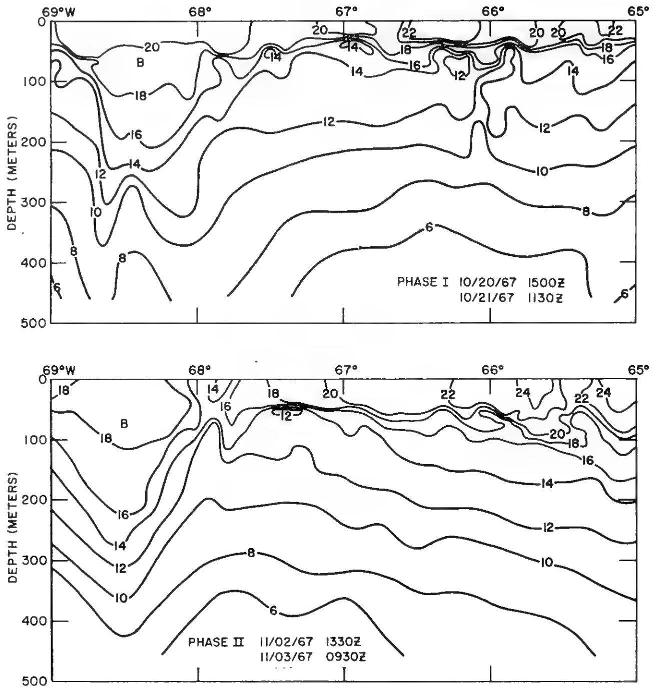


FIGURE 13 TEMPERATURE CROSS SECTIONS ALONG 39°20'N (°C)

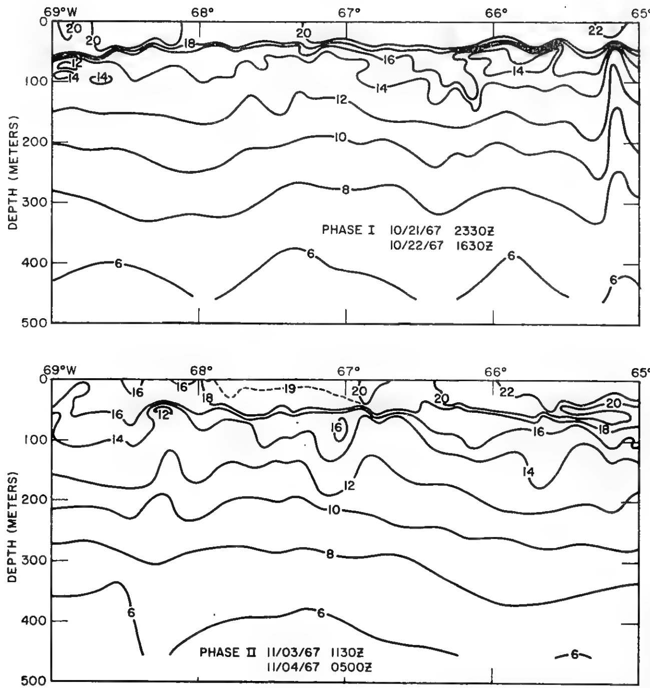


FIGURE 14 TEMPERATURE CROSS SECTIONS ALONG 39°00'N (°C)

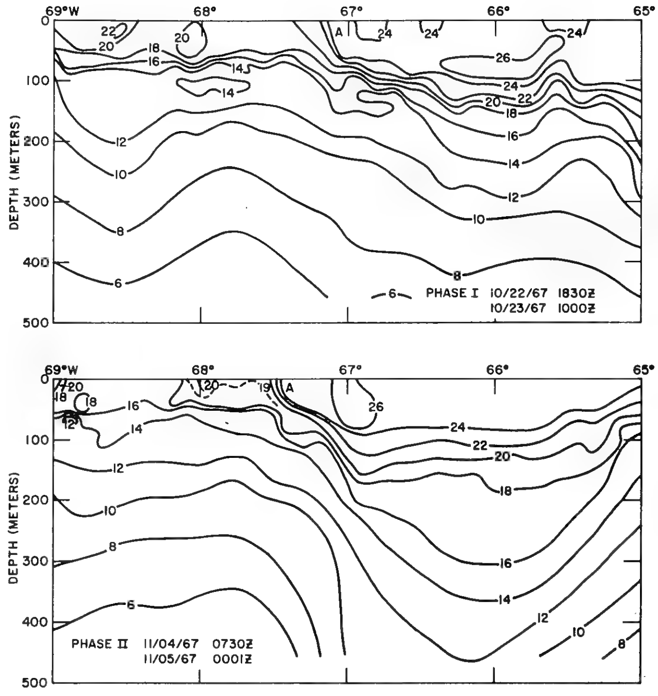


FIGURE 15 TEMPERATURE CROSS SECTIONS ALONG 38°30'N (°C)

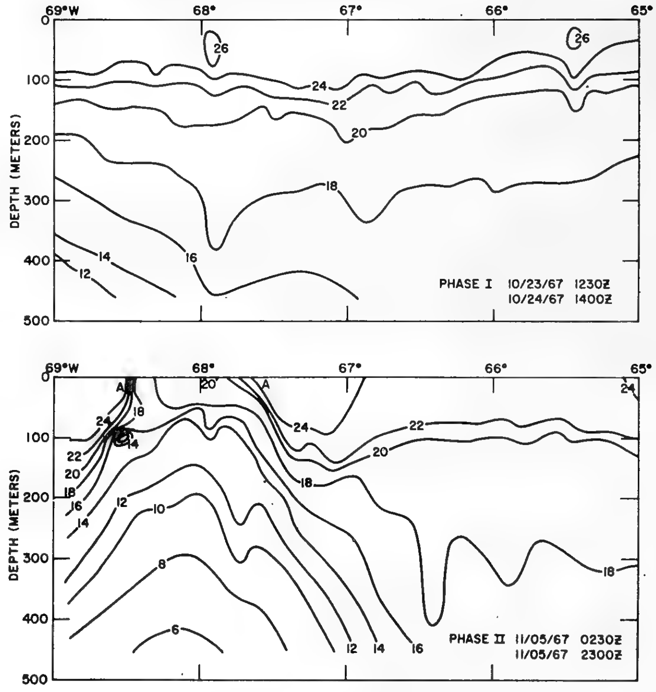


FIGURE 16 TEMPERATURE CROSS SECTIONS ALONG 38°00' N (°C)

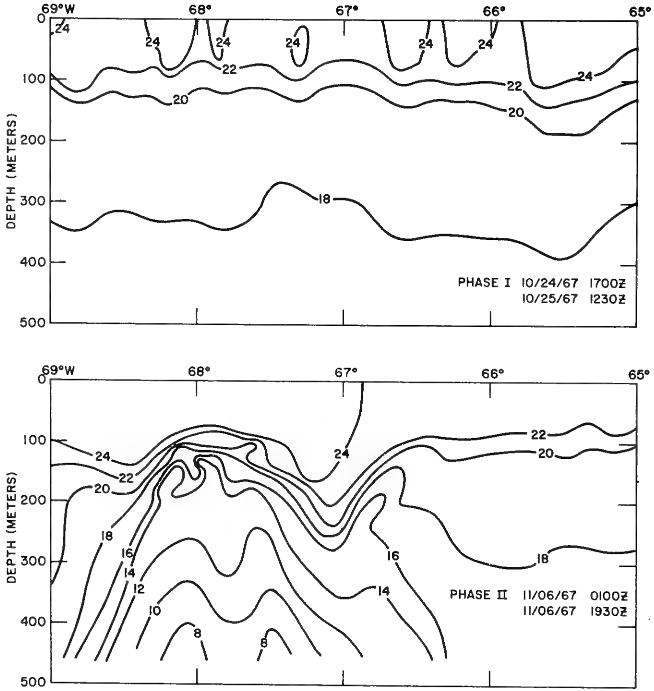


FIGURE 17 TEMPERATURE CROSS SECTIONS ALONG 37°30' N (°C)

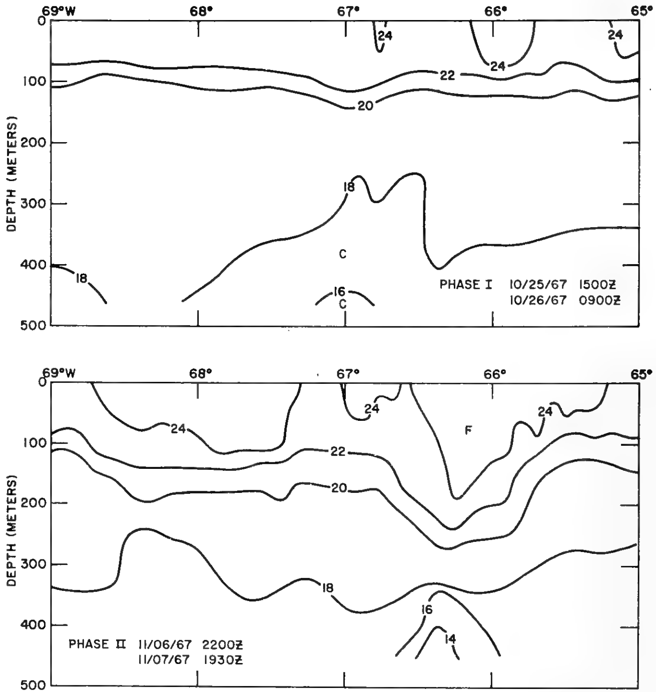


FIGURE 18 TEMPERATURE CROSS SECTIONS ALONG 37°00' N (°C)

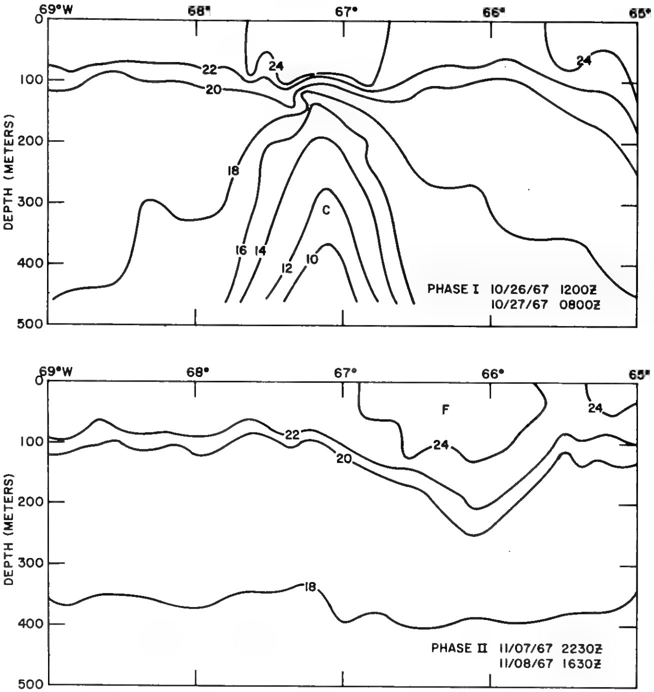


FIGURE 19 TEMPERATURE CROSS SECTIONS ALONG 36°30'N (°C)

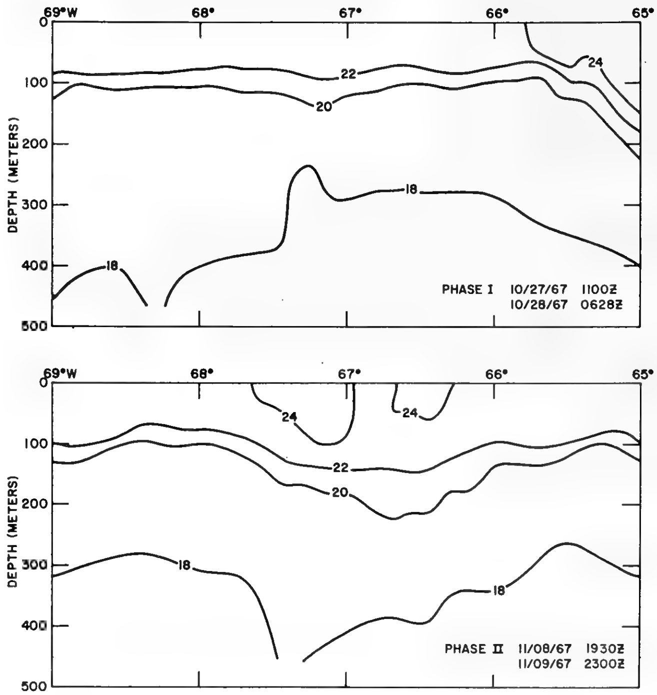


FIGURE 20 TEMPERATURE CROSS SECTIONS ALONG 36°00'N (°C)

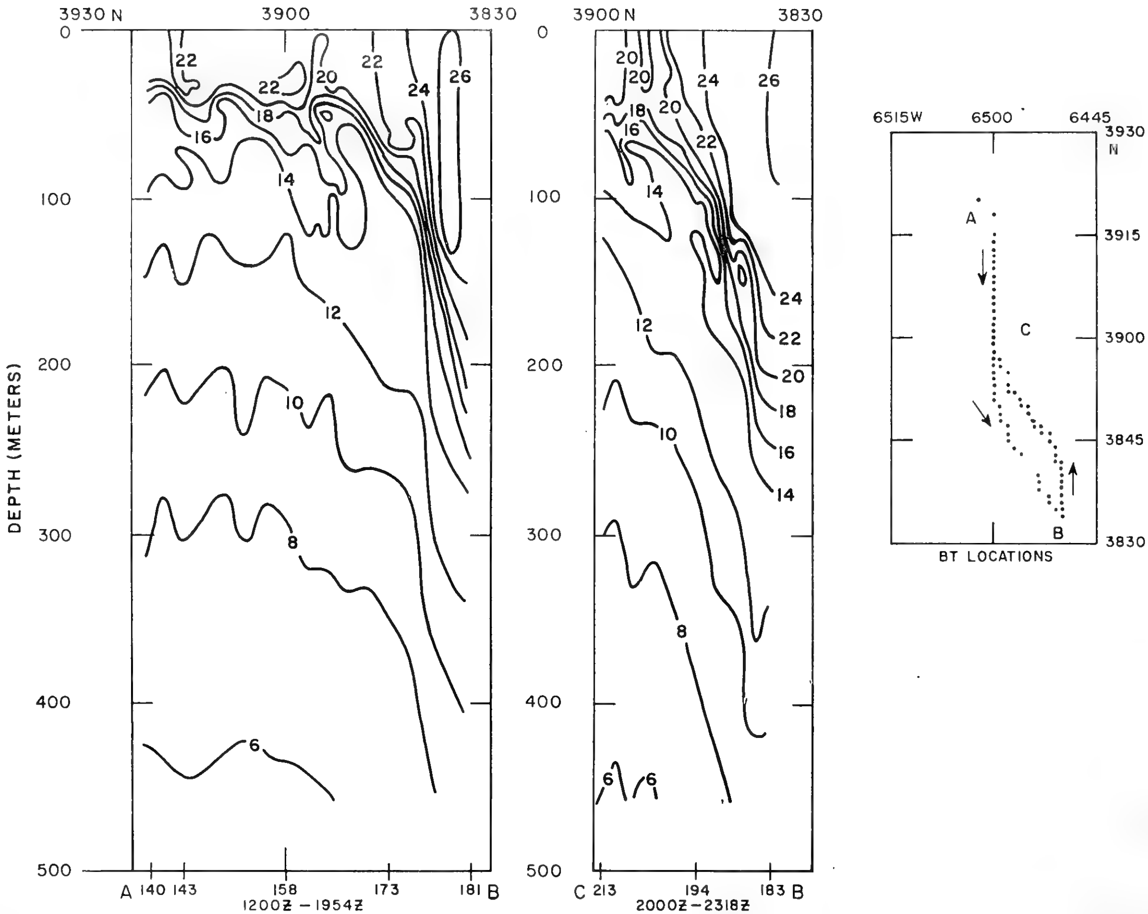
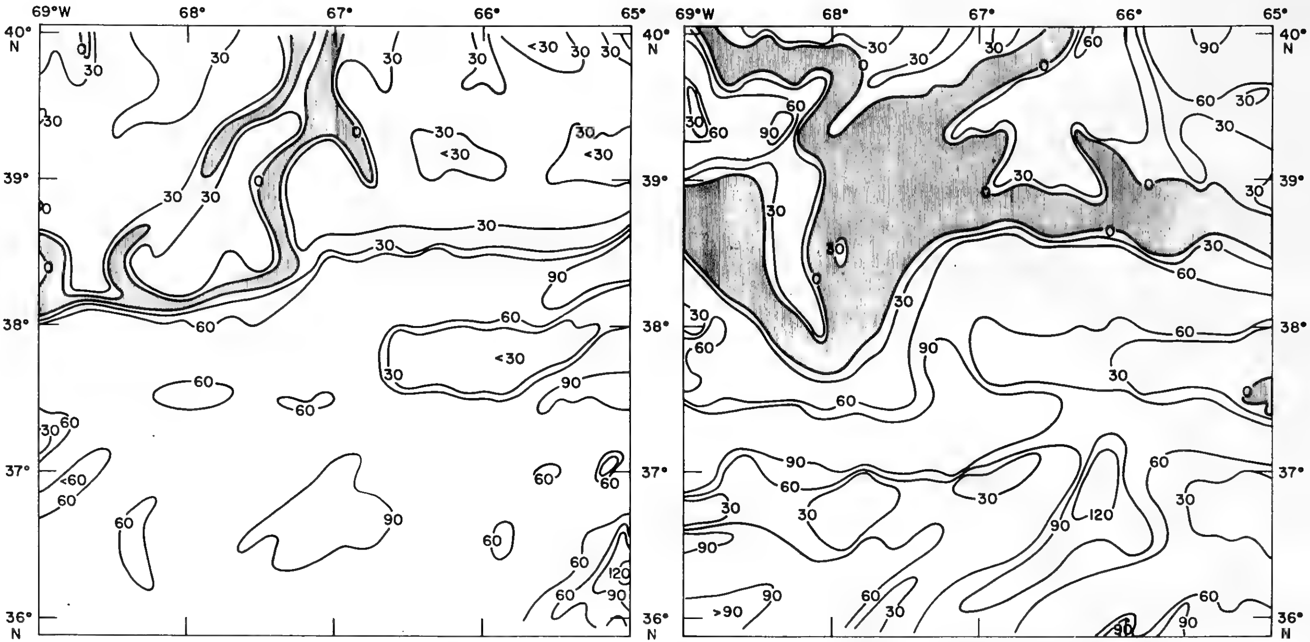


FIGURE 21 SECTIONS ACROSS GULF STREAM NEAR 65°W
21 OCTOBER 1967



PHASE I 17-28 OCTOBER 1967

PHASE II 31 OCTOBER-9 NOVEMBER 1967

FIGURE 22 COMPOSITE USNS GILLISS MIXED LAYER DEPTH ANALYSES (METERS)

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
U.S. Naval Oceanographic Office
Oceanographic Prediction Division
Marine Sciences Department

2a. REPORT SECURITY CLASSIFICATION
None

2b. GROUP
N/A

3. REPORT TITLE

Detailed Thermal Structure of the Western Gulf Stream Region

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Technical Report, ASWEPS Report No. 15

5. AUTHOR(S) *(First name, middle initial, last name)*
Bertrand J. Thompson
William H. Gemmill

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1968	25	7

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	TR-210
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	ASWEPS Report No. 15

10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
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Washington, D.C. 20390

13. ABSTRACT

Several thermal structure characteristics observed by oceanographic research vessels and aircraft are displayed and discussed. A series of airborne radiation thermometer (ART) flights conducted in April 1967 show detailed structure and pattern changes near the northern boundary of the Gulf Stream. Thermal changes were related to two contrasting weather patterns.

Since ART data define only surface temperature patterns, a ship survey was conducted in October and November 1967 to obtain vertically as well as horizontally distributed data. The ship survey was repeated, obtaining a total of almost 1,000 BT's. Cross sections of the data show that advection indicated by the ART survey extends to considerable depth. Three major features were observed: a meander developing in the Gulf Stream, a cold ring south of the stream, and a warm eddy north of the stream. The general flow was eastward, but a few features were found to drift westward.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
BATHYTHERMOGRAPH						
GULF STREAM						
OCEANOGRAPHIC DATA						
OCEANOGRAPHIC PREDICTION						
OCEANOLOGY						
WATER TEMPERATURE						

U.S. Naval Oceanographic Office
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UNCLASSIFIED

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